HETE Mission Update: Status and Scientific Highlights

George Ricker (MIT) and Don Lamb (U.Chicago)

on behalf of the HETE Science Team

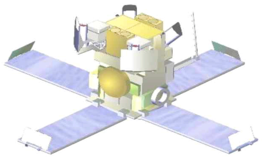
Structure and Evolution of the Universe Subcommittee (SEUS)

Inn and Conference Center, University of Maryland

Adelphi, Maryland

24 October 2003

http://space.mit.edu/HETE



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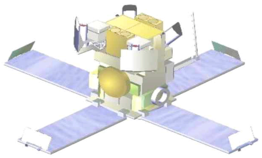


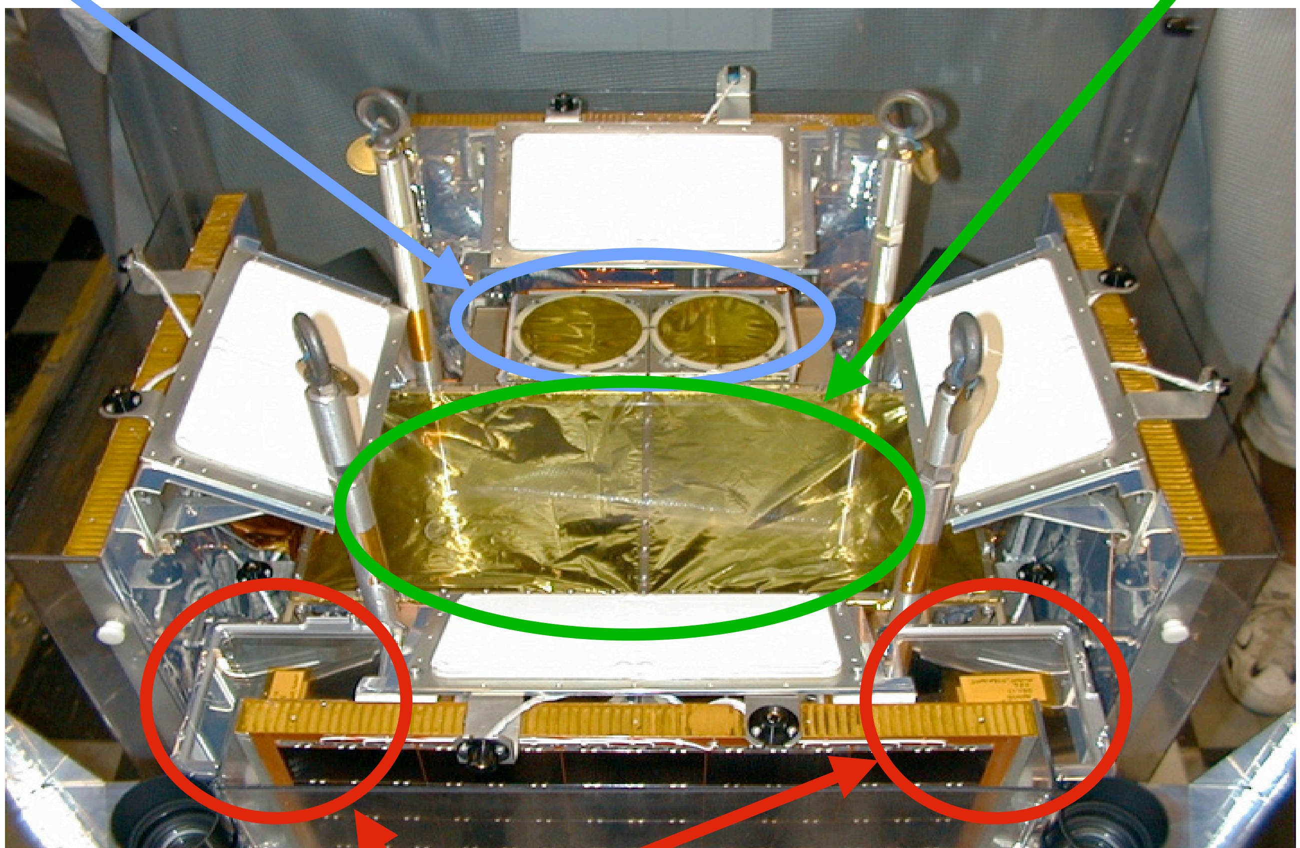
Outline of This Presentation

- Introduction
- Purpose of Our Presentation
- Scientific highlights of the HETE mission
- Current HETE Mission Status
- HETE Synergies with *Swift*
- Conclusions

HETE Science Instrument Package

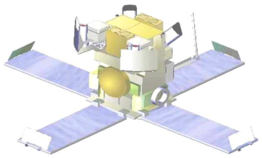
French Gamma-ray Telescope
(FREGATE): 5-500 keV; ~π FOV

Wide-Field X-ray Monitor **(WXM):**
2-25 keV; ~5'-10' localizations



Soft X-ray Cameras **(SXC):**

1-10 keV; ~30" localizations



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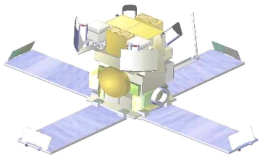

Purpose of Our Presentation

- The 2000 and 2002 Senior Reviews recommended that the HETE mission continue until 4-6 months after the launch of Swift – such an overlap period is critical for calibration, etc.
- HETE mission operations are currently scheduled to end on January 31, 2004, based on expectation of the 2002 Senior Review that Swift would have launched in September 2003
- Since the 2002 Senior Review, there have been three major changes:
  - During the past 1.5 years, HETE has performed at high level and produced outstanding science
  - *Swift* launch has been delayed until mid-May 2004
  - It has become clear from recent HETE discoveries about GRBs and XRFs that *the partnering of HETE and Swift* could significantly enhance the scientific return of the *Swift* mission
- In light of these changes, we are seeking :
  - Extension of the HETE mission operations through Summer 2004
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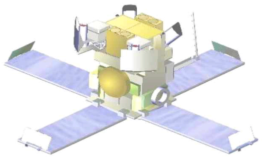
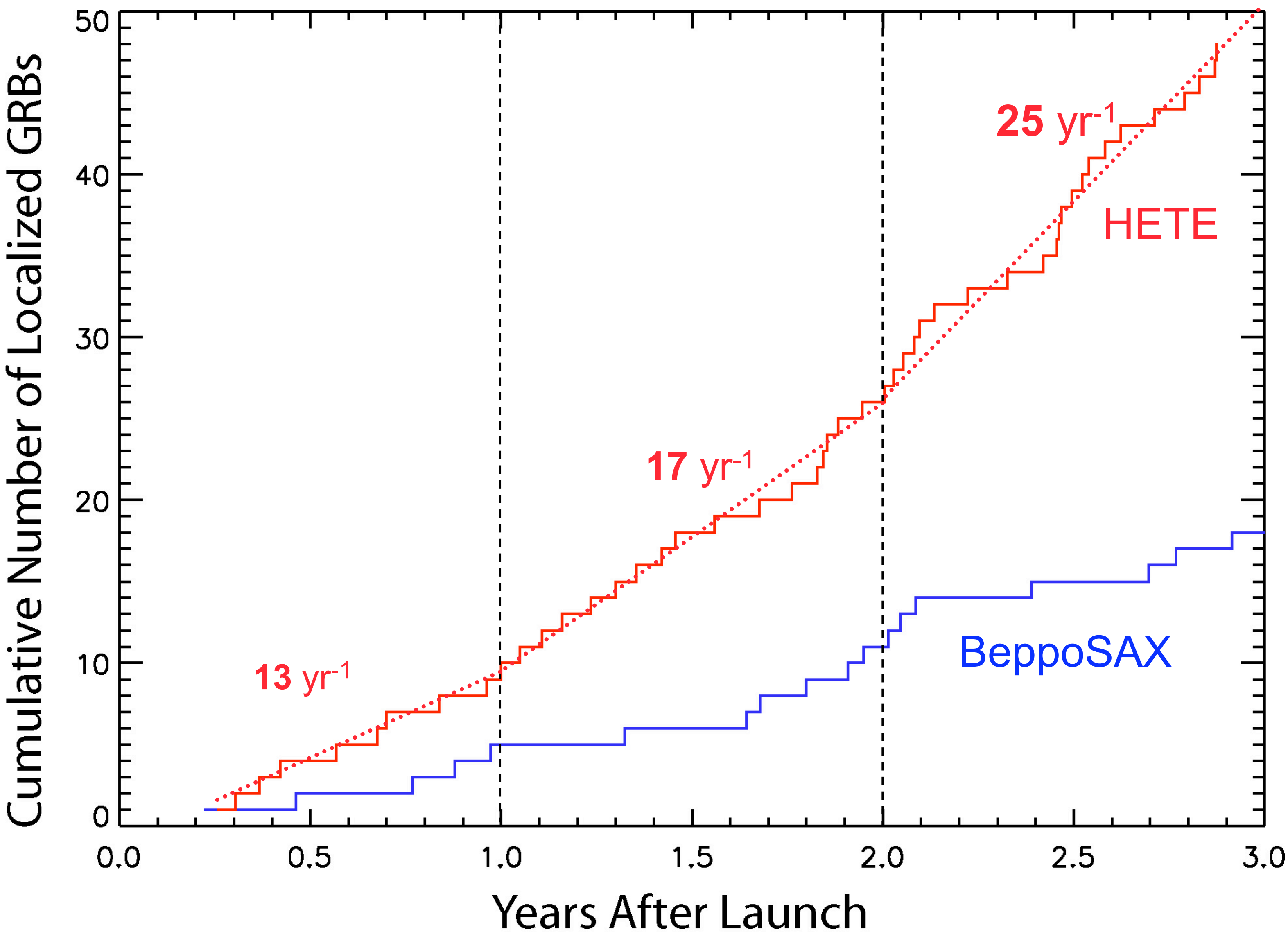


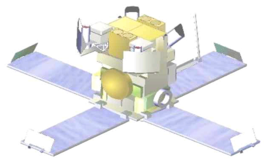
HETE is "Going Great Guns"

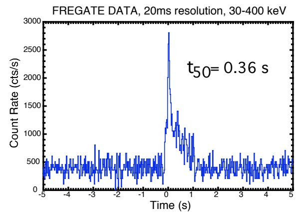
- HETE is currently localizing ~ 25 GRBs yr^{-1}
- HETE has localized 49 GRBs in 3 yrs of operation (compared to 52 GRBs localized by *Beppo*SAX during its 6-yr mission)
- 21 of these localizations have led to the detection of X-ray, optical, or radio afterglows
- As of today, redshifts have been reported for 12 of these afterglows (compared to 8 for *Beppo*SAX)
- HETE has localized 16 XRFs (compared to 17 for *Beppo*SAX)
- HETE has observed 45 bursts from SGRs 1806-20 and 1900+14 in the summers of 2001- 2003 – and discovered a 6th SGR: 1808-20
- HETE has observed ~ 1000 XRBs

Cumulative GRB Localizations by HETE and BeppoSAX

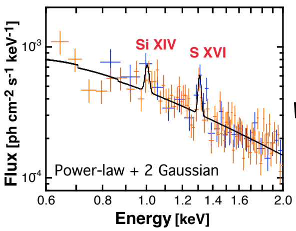


HETE Gamma-ray Bursts:
6 Major Scientific Insights in Past 1.5 Years

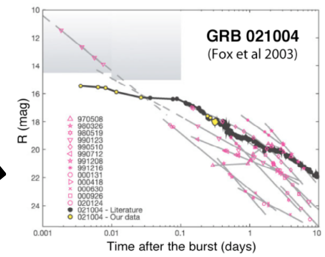




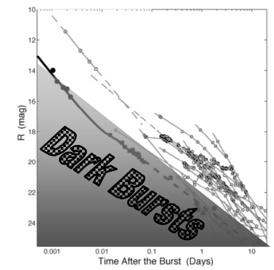
GRB020531:
First detection of short GRB with prompt optical/X-ray followup



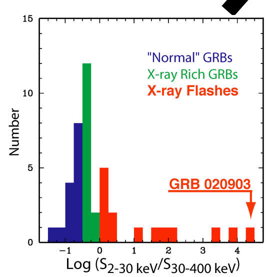
GRB020813:
X-ray lines from
 particle nuclei
(Chandra spectra)



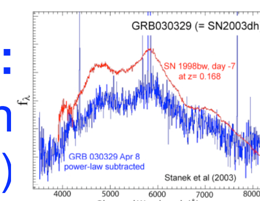
GRB021004:
Refreshed shock
or inhomogeneous jet
(NASA SSU)



GRB021211:
Insight into "Optically Dark" GRB Mystery

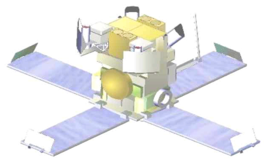


GRB020903:
Elucidation of
"X-ray Flashes"



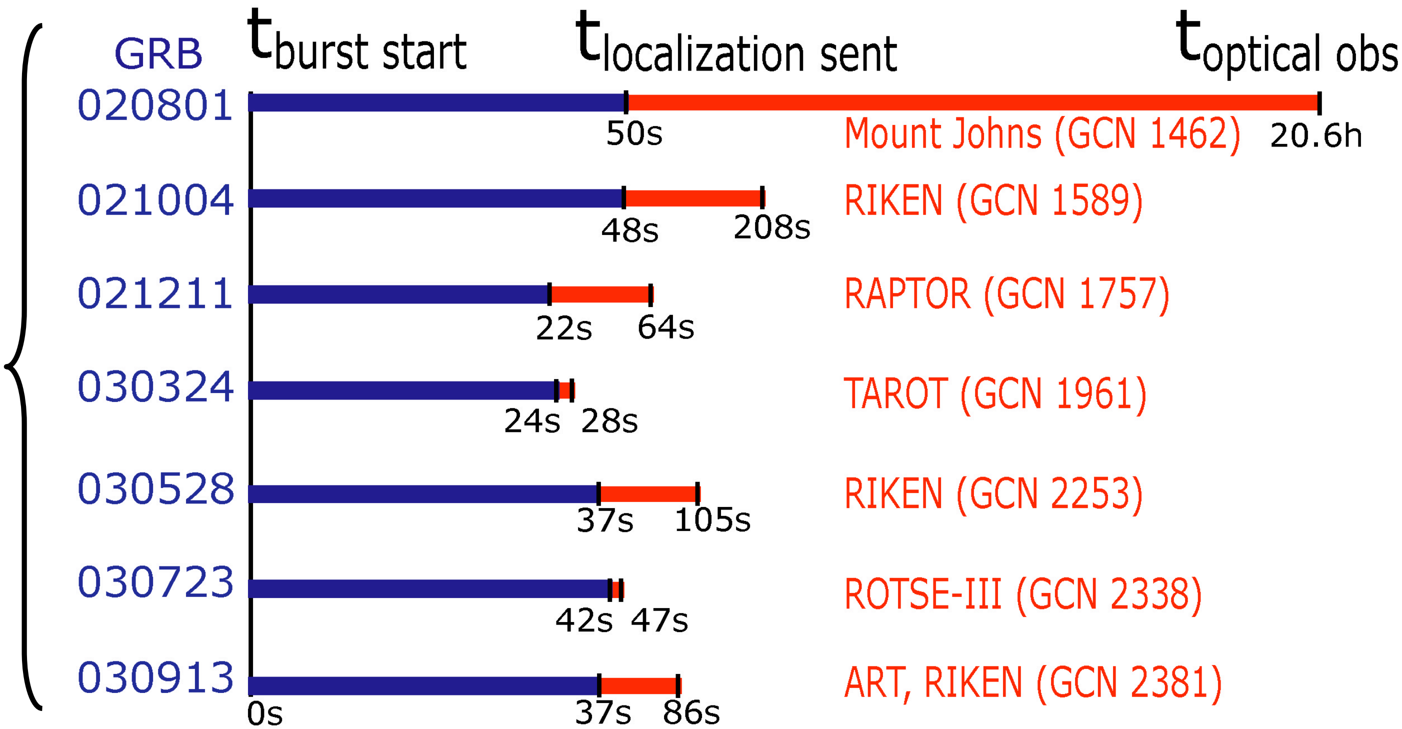
GRB030329:
GRB-SN Connection
(SN2003dh; z=0.17)

HETE



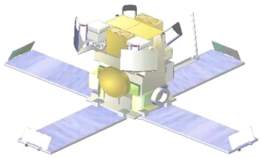
Time Delays in Dissemination of 28 HETE Localizations & Optical Follow-ups

7 GRBs with t<60s localization delay in past 1.25 years (all since SR'02)



NB: 3 of 7 were promptly followed up from downtown Tokyo!

- **For the 28 GRBs localized by HETE in past 1.5 years,**
  - **7 localizations with t <60s (25%)**
  - **3 localizations with 60s<t<10m (11%)**
  - **2 localizations with 10m<t<1h (7%)**
  - **16 localizations with t >1h (57%)**



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- **Current HETE Mission Status**
  - **SXC results: Solving the Dark GRB problem**
  - **XRFs: HETE’s forte**
  - **Satellite + Instruments operating smoothly**
- HETE Synergies with *Swift*
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Restoration of HETE Soft X-ray Camera (SXC)

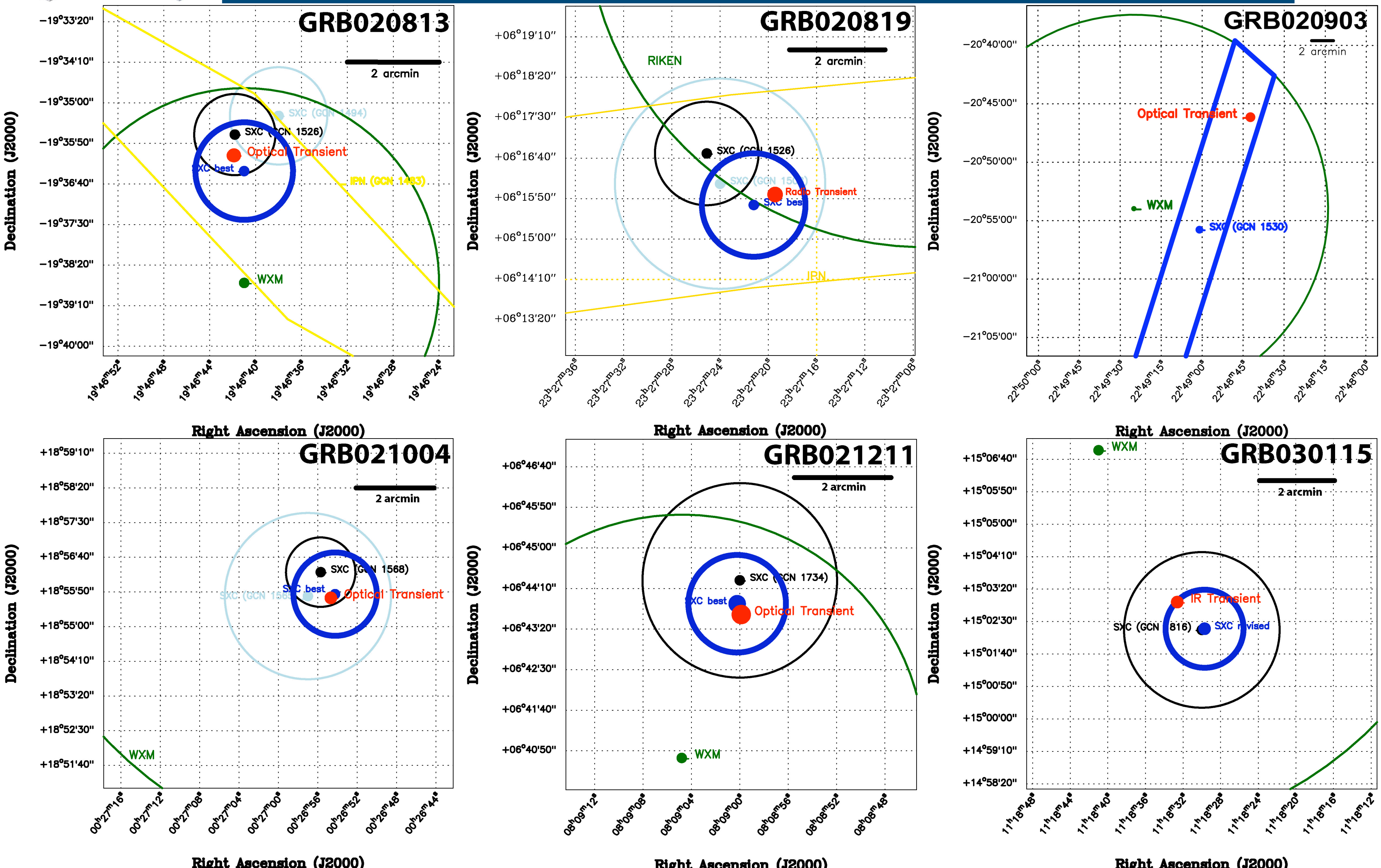
- Outer optical blocking filter (OBF) eroded by atmospheric atomic oxygen 4 months into mission.

- X-ray Event Flight Code modified to correct for light leak:

- Code completed in April 02; tested in Summer ‘02

- SXC fully functional after code changed
  (but too late for Senior Review 2002…)

Recent Localizations with HETE SXC (1 of 2)



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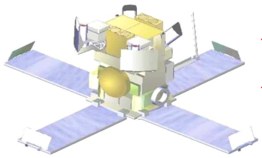
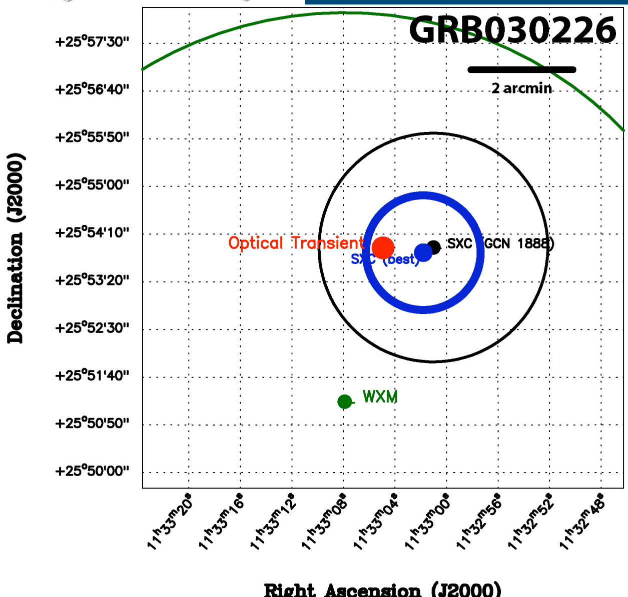
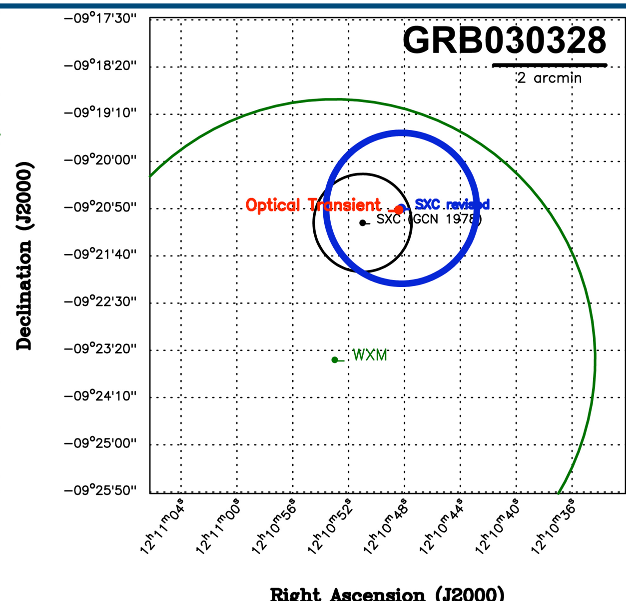
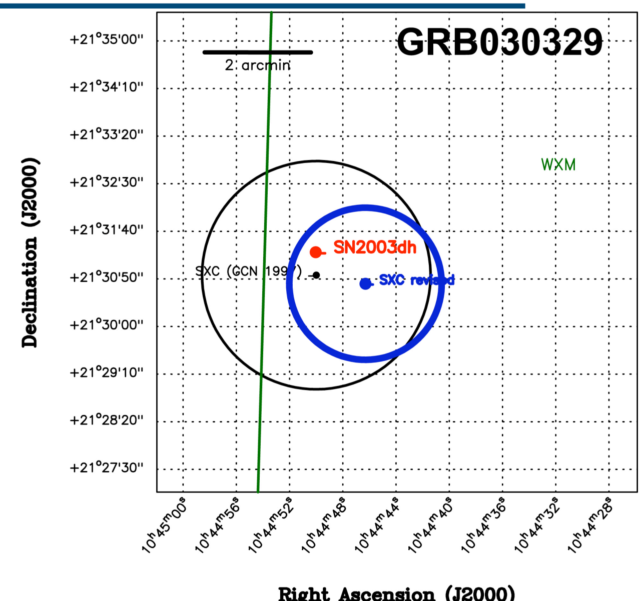
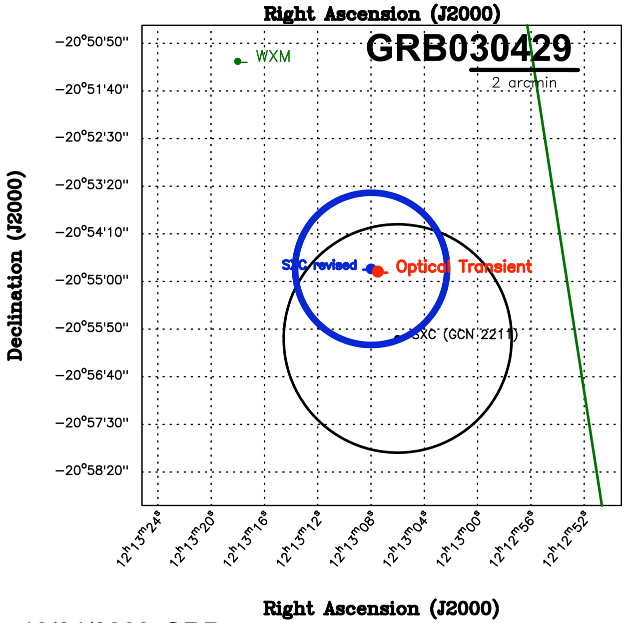


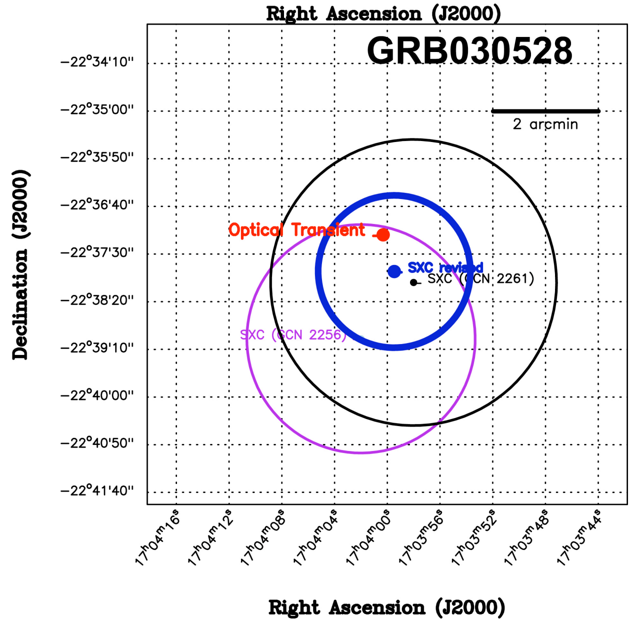
Recent Localizations with HETE SXC (2 of 2)

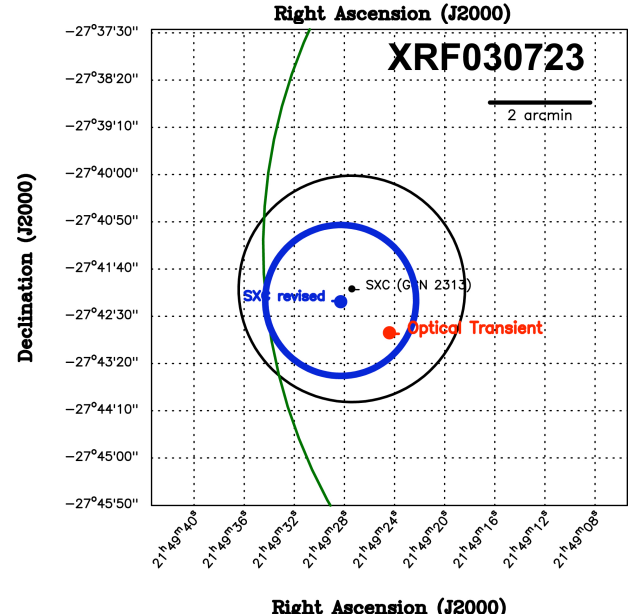


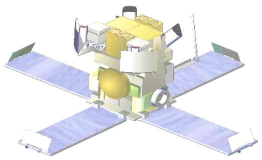












HETE's Latest Hits: SXC Localizations in the Past Year…

GRB	Localization	Error radius	Offset*	Afterglow?	Redshift	Burst type
020813	2D	50"	25.6"	O, IR, R, X	1.25	GRB
020819	2D	64"	97.9"	R	–	X-ray rich
020903	1D	120"	70.6" (1D)	O, R	0.25	XRF
021004	2D	62"	39.9"	O, IR, R, X	2.30	X-ray rich
021211	2D	120"	42.2"	O, IR	1.01	X-ray rich
030115	2D	120"	57.2"	O, IR, R	–	X-ray rich
030226	2D	120"	52.8"	O, IR, X	1.98	X-ray rich
030323	1D	120"	15.4" (1D)	O	3.37	GRB
030328	2D	52"	40.7"	O, X	1.52	GRB
030329	2D	120"	24.1"	O, IR, R, X	0.17	X-ray rich
030429	2D	120"	73.2"	O, IR	2.65	XRF
030528	2D	150"	59.3"	IR, X	–	GRB
030723	2D	120"	61.2"	O, X	–	XRF
030725	1D	120"	126.4" (1D)	O	–	GRB
030823	2D	120"	?	?	–	X-ray rich

***SXC Error Circle Center to Afterglow Counterpart (in arcseconds)**

X = Chandra observation

–**15** SXC localizations (= 3 XRF + 7 XRR + 5 GRB)

– **9** of **15** = **60%** of SXC localizations have redshifts

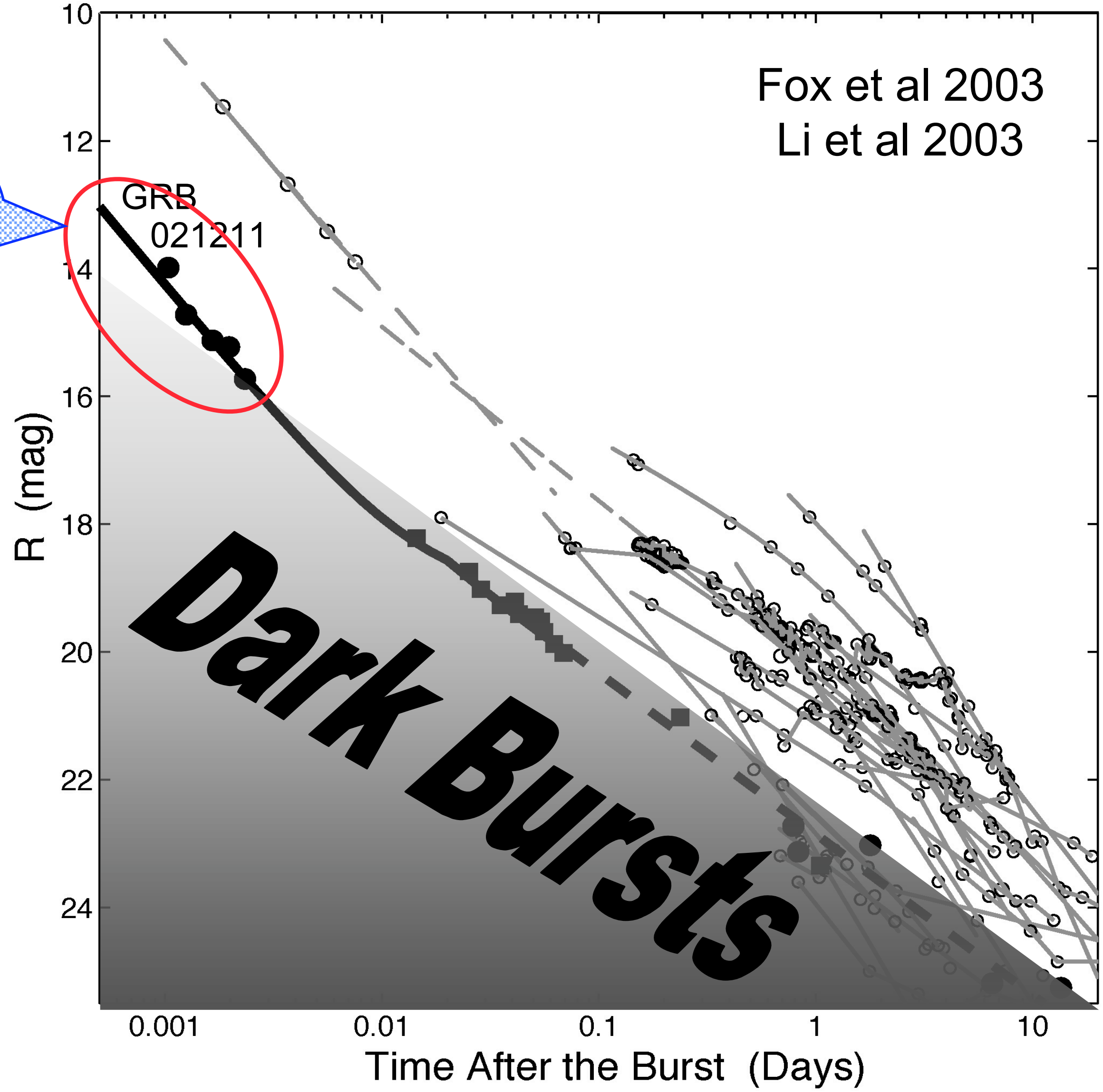
–**13** of **15** = **87%** of SXC localizations have optical (or near IR) counterparts

ie *No more "optically dark" GRBs?*

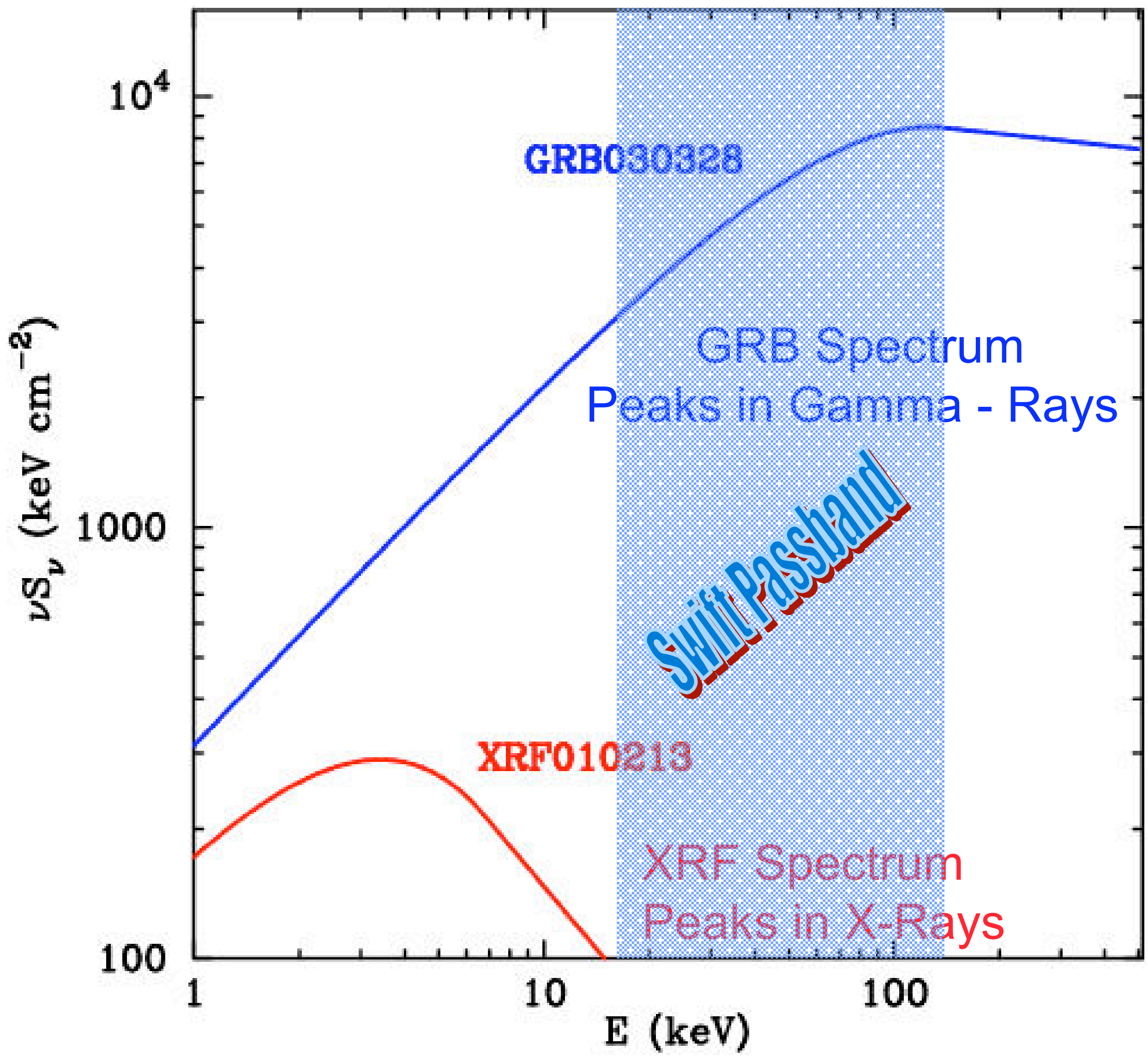
SXC Localization rate = ~15 yr^{-1} (ie ~2/3 rate of HETE WXM)

GRB021211: An *Optically Faint* GRB Caught Early?

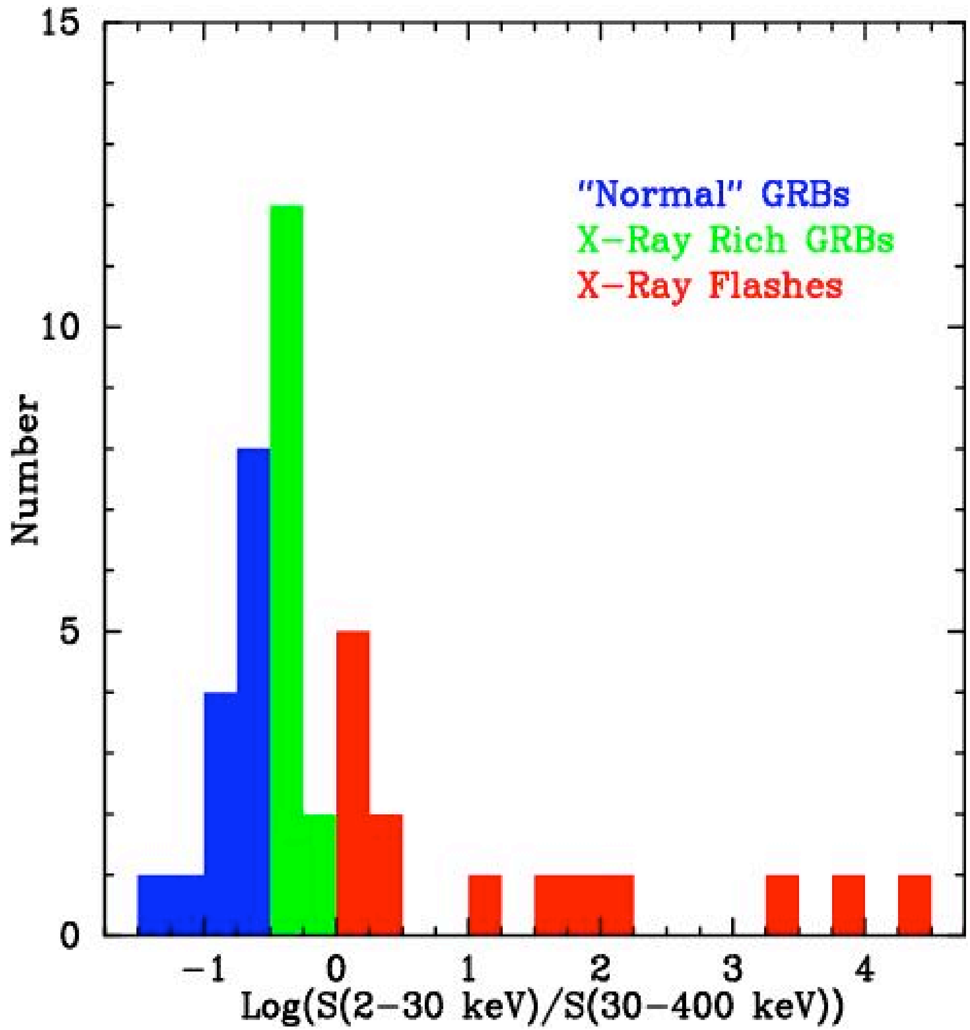
HETE's enabling this part made the difference!



HETE-2 X-Ray Flashes vs. GRBs



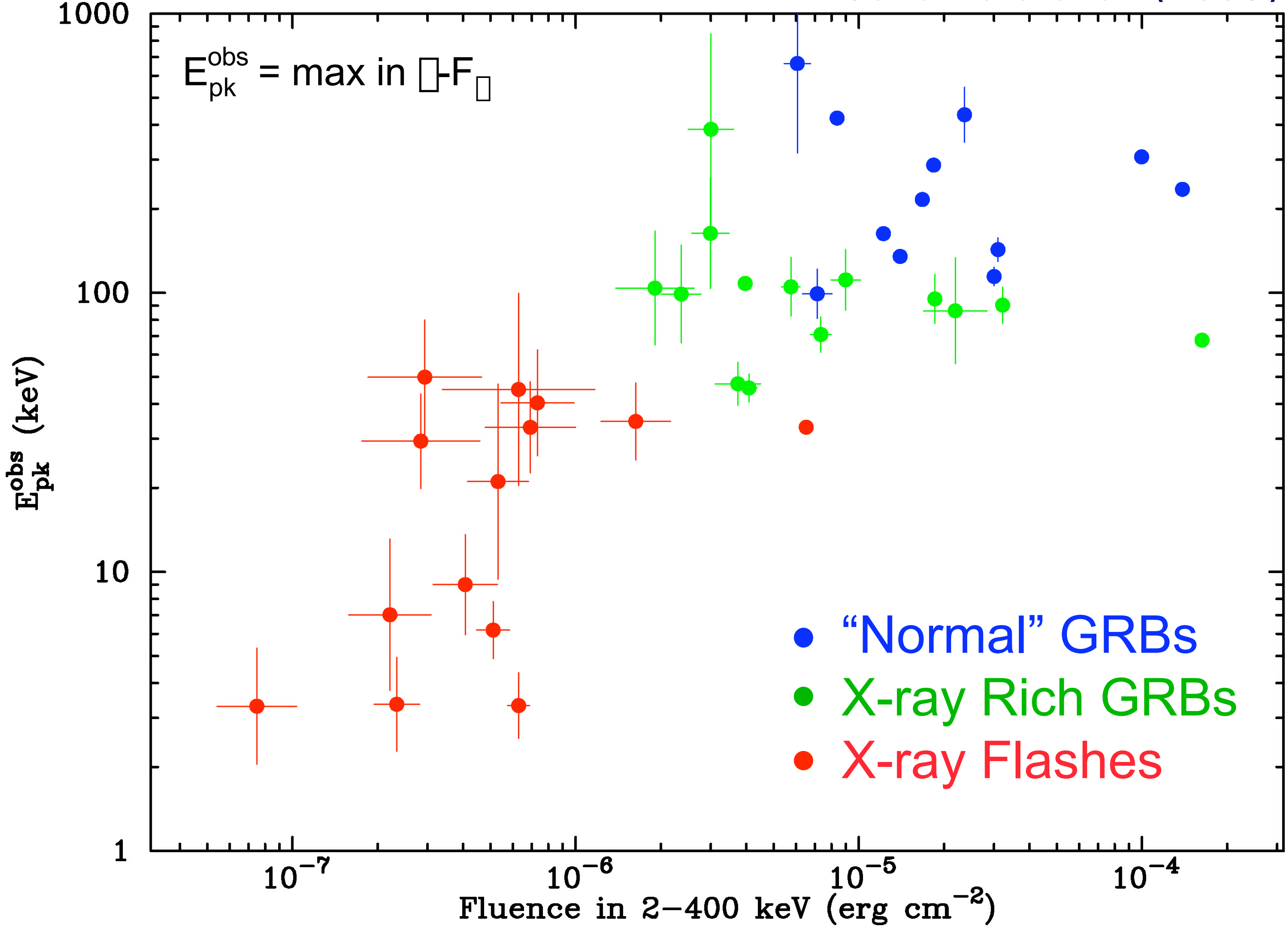
X-Ray Flashes Discovered by HETE



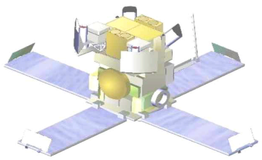
- Of the HETE bursts
  - 1/3 are XRFs
  - 1/3 are "X-ray-rich" GRBs
  - 1/3 are "classical" GRBs
- Nature of XRFs is largely unknown
- HETE-discovered XRFs may provide unique insights into:
  - Structure of GRB jets
  - GRB rate
  - Nature of Type Ic supernovae

Density of HETE Bursts in (S, E_{peak})-Plane

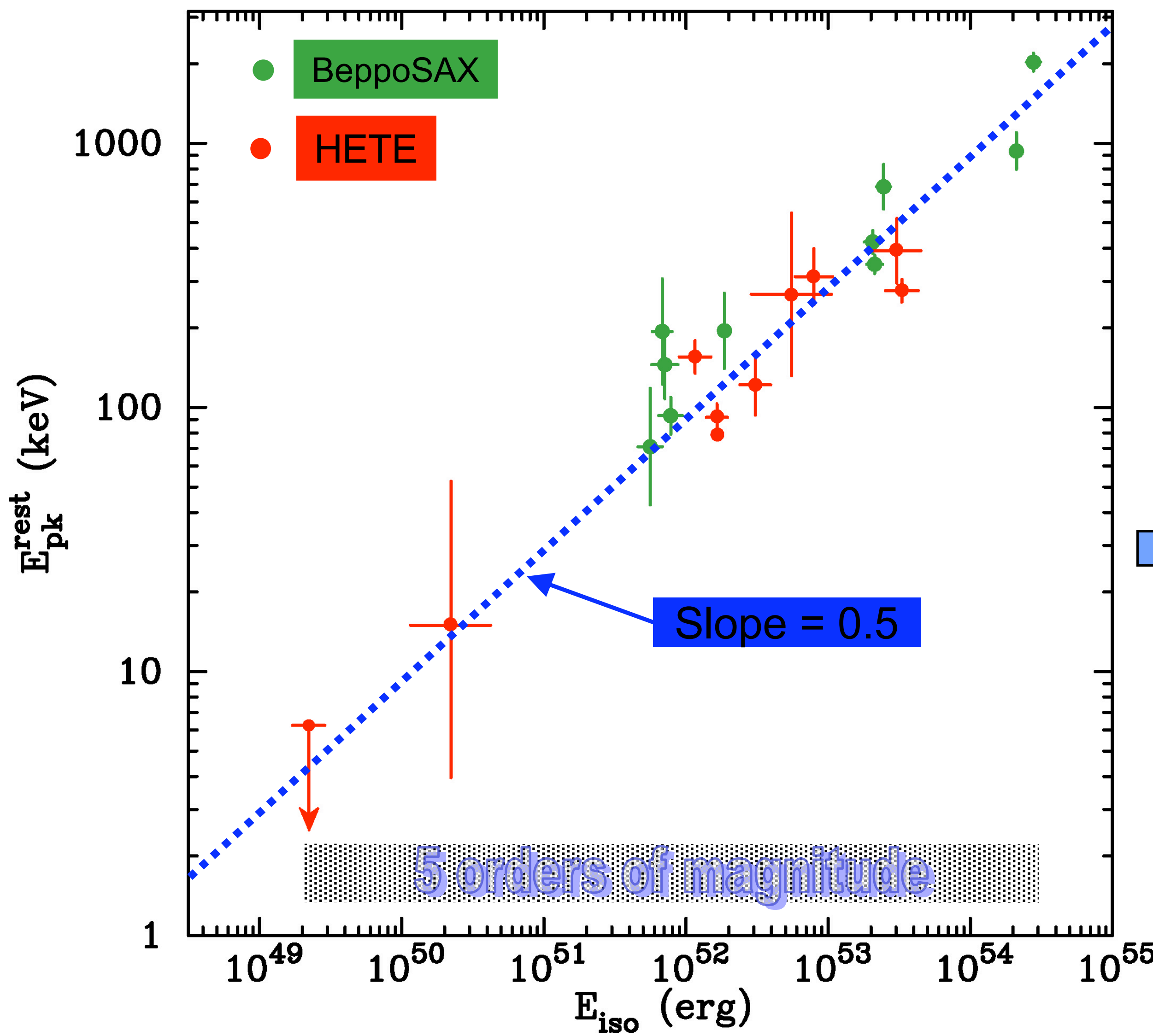
Sakamoto et al. (2003)



HETE



Dependence of GRB Peak Spectral Energy (E_{peak}) on Burst Isotropic Radiated Energy (E_{iso})

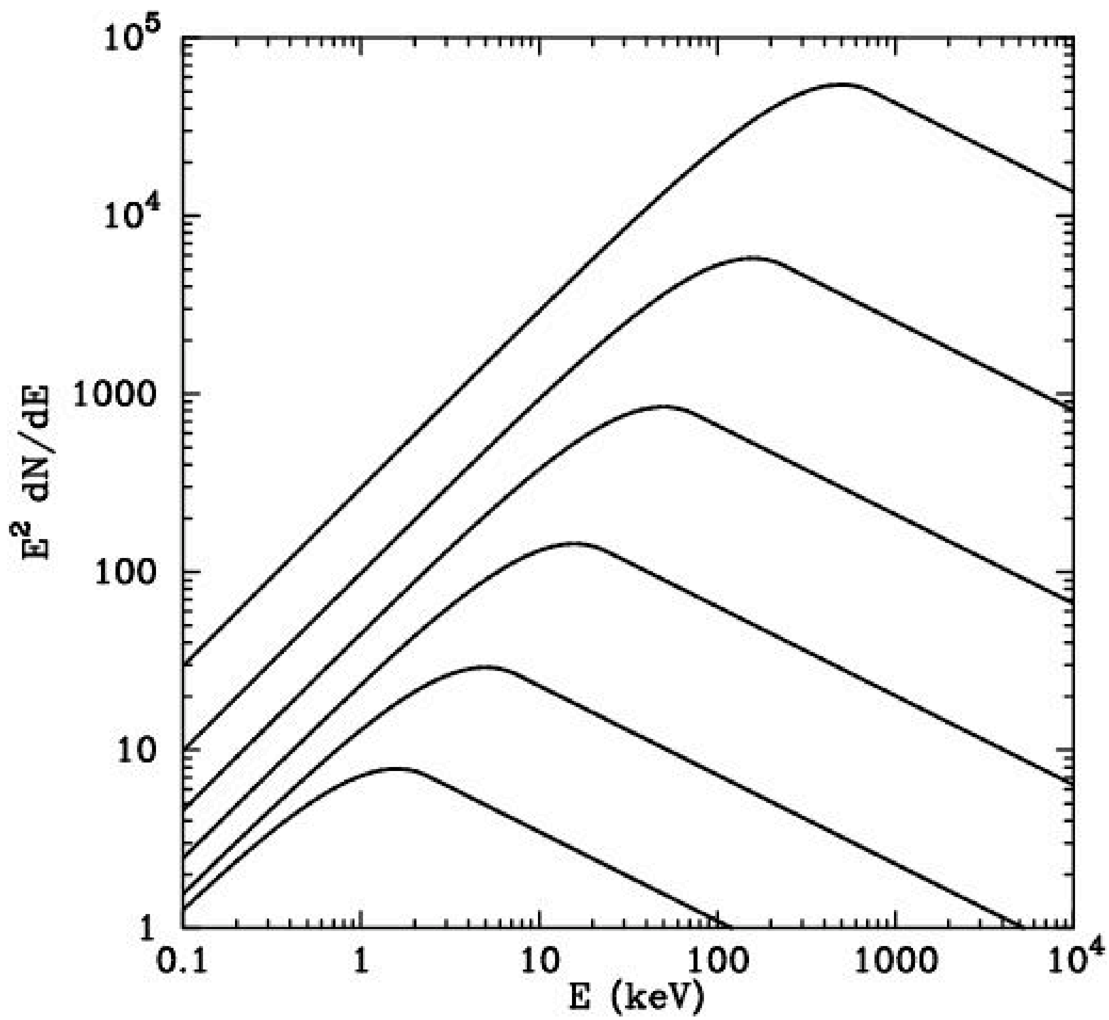


HETE results confirm & extend the Amati et al. (2002) rel'n:

$$E_{peak} \sim \{E_{iso}\}^{0.5}$$

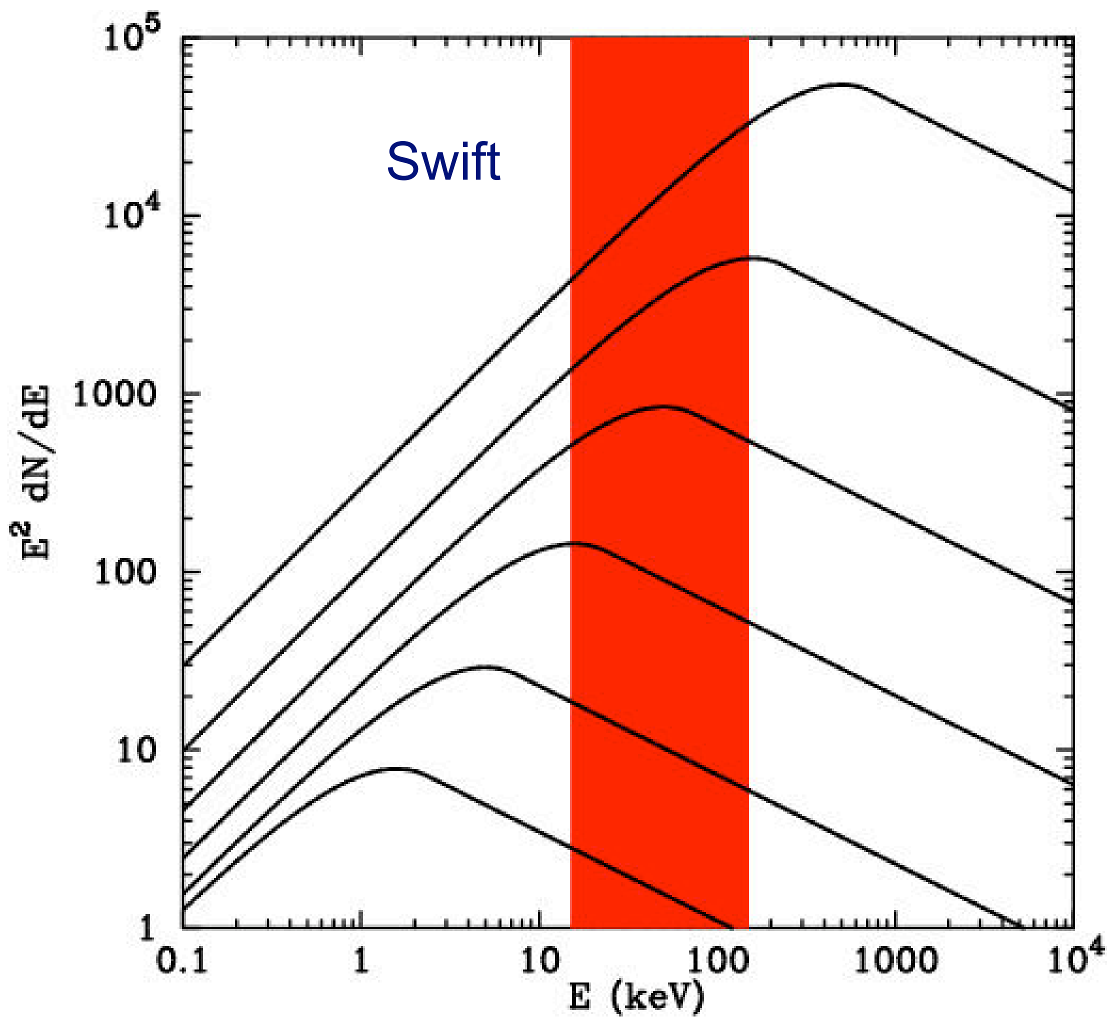
GRB spectra can provide an empirical, predictive *redshift estimator* that is accurate to a factor of ~2 (Atteia 2003).

X-Ray Flash → GRB Spectra



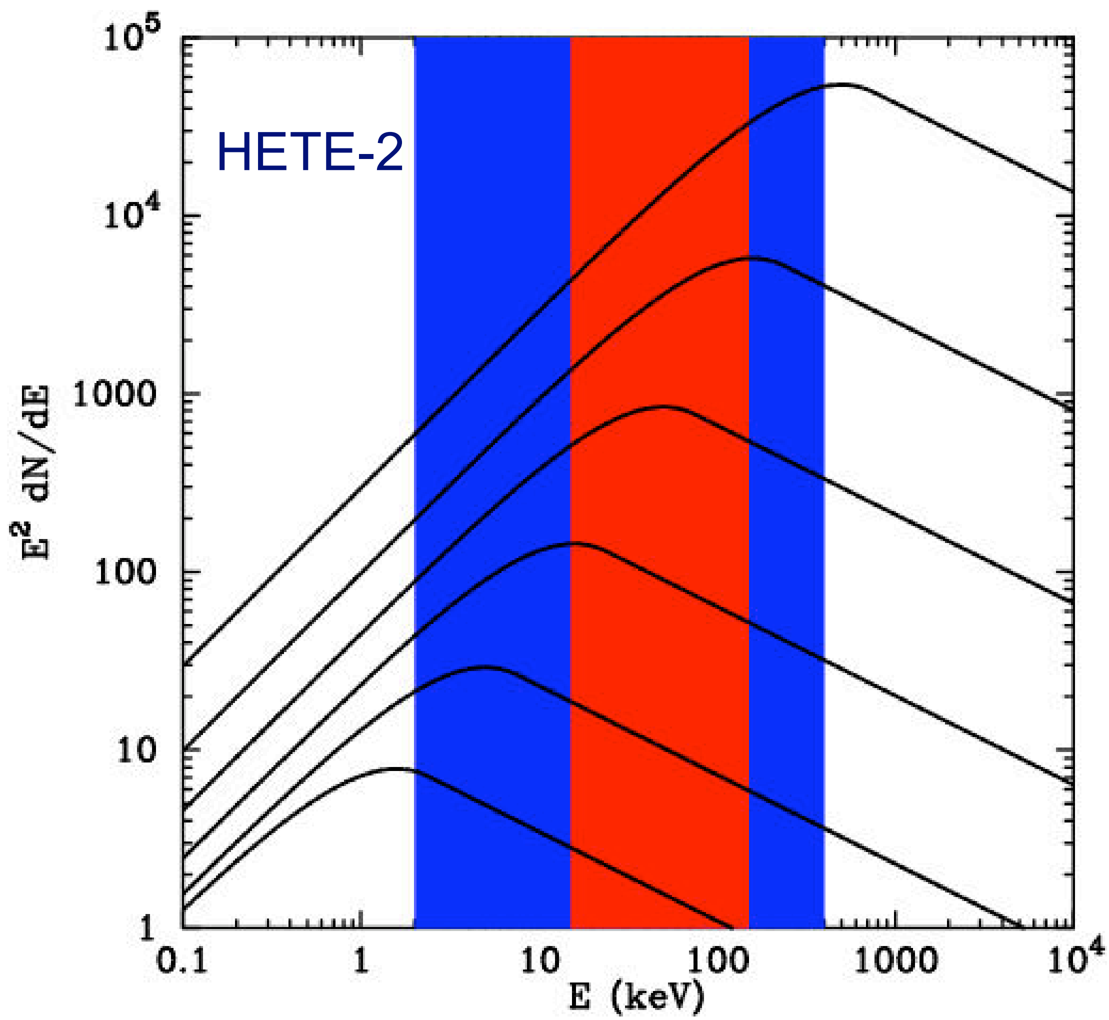
- Going from XRFs to GRBs, E_{peak} = 1 keV → 300 keV
- Determination of E_{iso}, and *especially* E_{peak}, requires broad energy coverage

X-Ray Flash → GRB Spectra

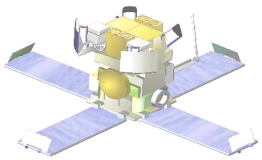


- *Swift* is designed to exploit the tremendously important science that can come from the X-ray, optical, and radio afterglows of GRBs
  - *Swift* will do this spectacularly well
  - XRT and UVOT follow-up observations will increase greatly the no. of GRBs w. redshift determinations

X-Ray Flash → GRB Spectra

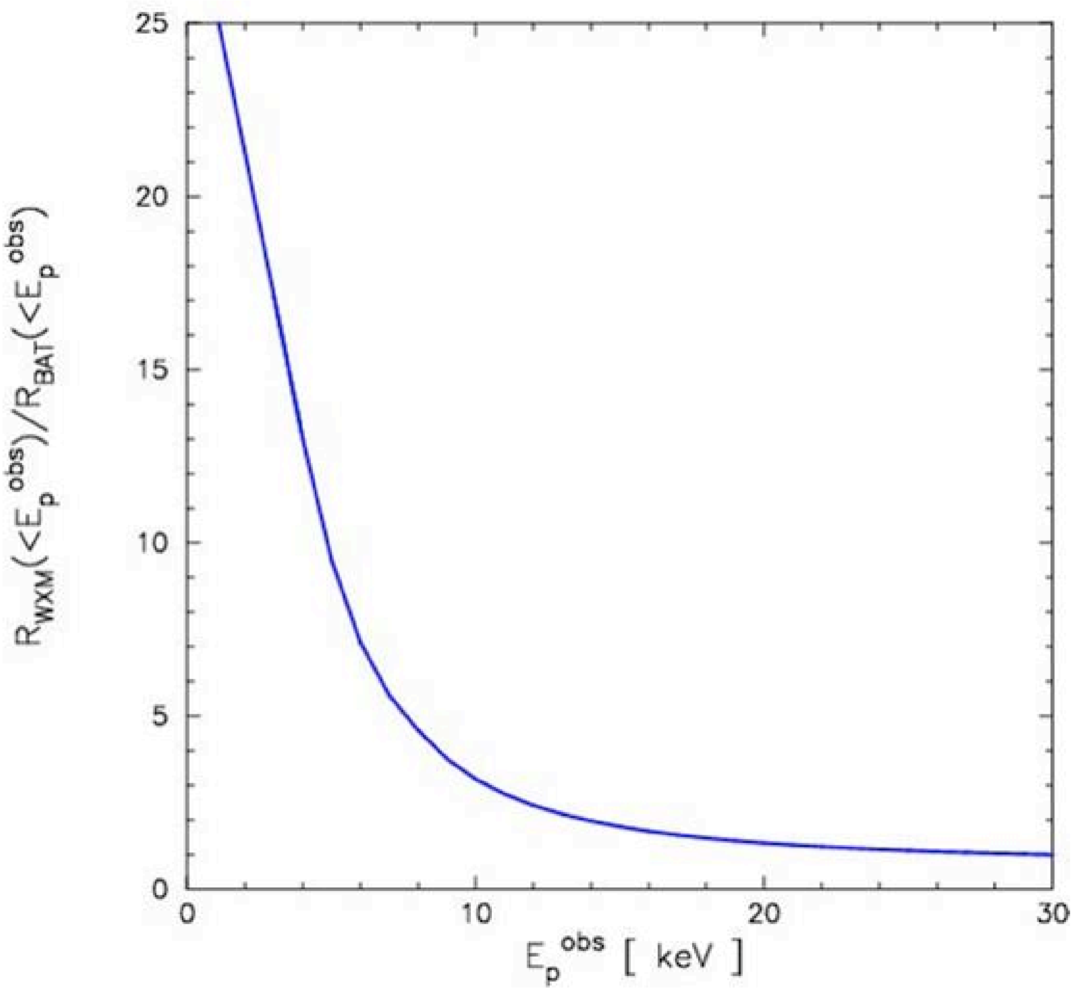


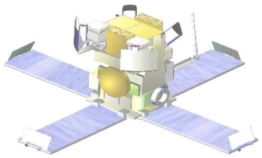
- HETE-2 is designed to study GRB spectra
- Working together, HETE-2 and *Swift* can get *both* spectra and z for HETE-2 bursts that Swift slews to
- This is *crucial* to confirm that the E_{iso} – E_{peak} relation extends to XRFs, and to confirm that E_{iso} evolves strongly w. redshift



HETE Is Ideally Suited to Localize and Study XRFs

- **HETE instruments have**
  - **Energy thresholds 1-6 keV**
  - **Considerable effective area in X-ray energy range**
- **BAT on Swift has nominal threshold of ~ 15 keV**
- **Relative rate of detection of XRFs by HETE and Swift is**
  - **3 for E_peak's < 10 keV**
  - **10 for E_peak's < 5 keV**
- **Ability of HETE to localize and study XRFs constitutes a compelling reason for continuing HETE during the *Swift* mission**





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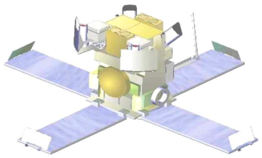
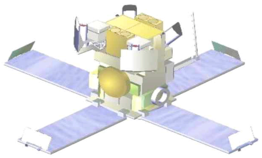


HETE Synergies with Swift

- **HETE can ~ double number of very bright GRBs at z < 0.5 that *Swift* XRT and UVOT can follow up – *these bursts are crucial for understanding the GRB – SN connection***
- **HETE can ~ double number of bright GRBs at z > 5 that *Swift* can follow up – *these bursts are crucial for using GRBs as probe of very high z universe***
- **HETE can increase**
  - **by factor ~ 3 the number of XRFs w. E_{peak} < 10 keV and**
  - **by factor ~ 10 the number of XRFs w. E_{peak} < 5 keV**

  that *Swift* can follow up – *these bursts are crucial for determining nature of XRFs, structure of GRB jets, GRB rate, relationship between GRBs and Type Ic SNe)*
- **HETE can provide bolometric F_{peak}, S, and spectral parameters (E_{peak}) for HETE bursts that *Swift* can follow up – *this is crucial for confirming E_{iso}-E_{peak} relation extends to XRFs and for confirming strong GRB evolution w. redshift)***



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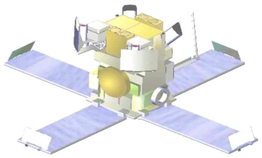


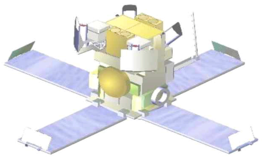
Senior Review 2000 HETE Assessment

Strengths
HETE-2 is using an innovative concept to provide accurately localized positions of GRBs to the international scientific community within seconds of their discovery. The satellite team has very successfully established a network of twelve Burst Alert Stations which provides a 90% temporal coverage for GRB follow-up observations across the globe. During its eighteen month mission, HETE-2 will enhance the number of known GRB redshifts by at least a factor of 2 and provide invaluable input towards the determination of the GRB luminosity function. Furthermore, HETE-2 is uniquely equipped to detect afterglows of short GRBs for the first time, thus probing the properties of a potentially different GRB class.

The requested extended HETE-2 mission will provide a larger sample of bursts by a factor of 2 and scientific and programmatic continuity in the field until the launch of Swift, a GRB dedicated MIDEX mission. **The six month suggested overlap between HETE-2 and Swift is necessary to afford instrument cross-calibration**. **In addition, a HETE-2 extended mission is cost effective and will provide a safety net for potential Swift launch delays and/or failure.**

Weaknesses
The continuity afforded during an extended mission will improve the quantity of data but is not likely to lead to new breakthroughs.

Recommendation
We recommend an extended lifetime mission for HETE-2 through 2004. The HETE-2 scientific team should ensure heritage of their experience, with their world-wide network of support and their operating system, to the Swift team. During the extended mission, we recommend that all data products of HETE-2 be immediately available to the public.



Senior Review 2002 HETE Assessment

Extended Mission Strengths

HETE-II fills a gap in the gamma-ray burst detection studies between the recent end of operations of the Italian SAX mission and the beginning of science from NASA's Swift mission in 2004. This is particularly important for continuity in the worldwide ground-based burst follow-up enterprises, and was emphasized by the 2000 Senior Review. There is a **good expectation that HETE-II will produce scientifically valuable and new insights into two classes of bursts: X-ray rich bursts and short-hard bursts.** The HETE-II satellite and ground-based Burst Alert Network typically notify the worldwide community via Internet within 30 seconds of the arrival time (but not location) of a burst. This rapid response is critical for investigation of burst behaviors and physics with ground-based robotic telescopes.

Extended Mission Weaknesses

At its current level and over a 2-year Extended Phase, about 200 bursts are expected to be detected with the FREGATE instrument; 40 will be roughly (typically 10'-20') localized with the Wide-Field X-ray Monitor; 6-10 will be finely (<1') localized with the Soft X-ray Camera. This performance means that only a modest number of bursts can be confidently identified and studied at optical wavelengths. With the exception of interesting constraints on the properties of the soft gamma-ray repeater 1900+14, the level of new scientific results that has emerged from the first 17 gamma-ray bursts detected with HETE-II has been limited. Much of the phenomenology derived from HETE-II data is comparable in quality to existing data.

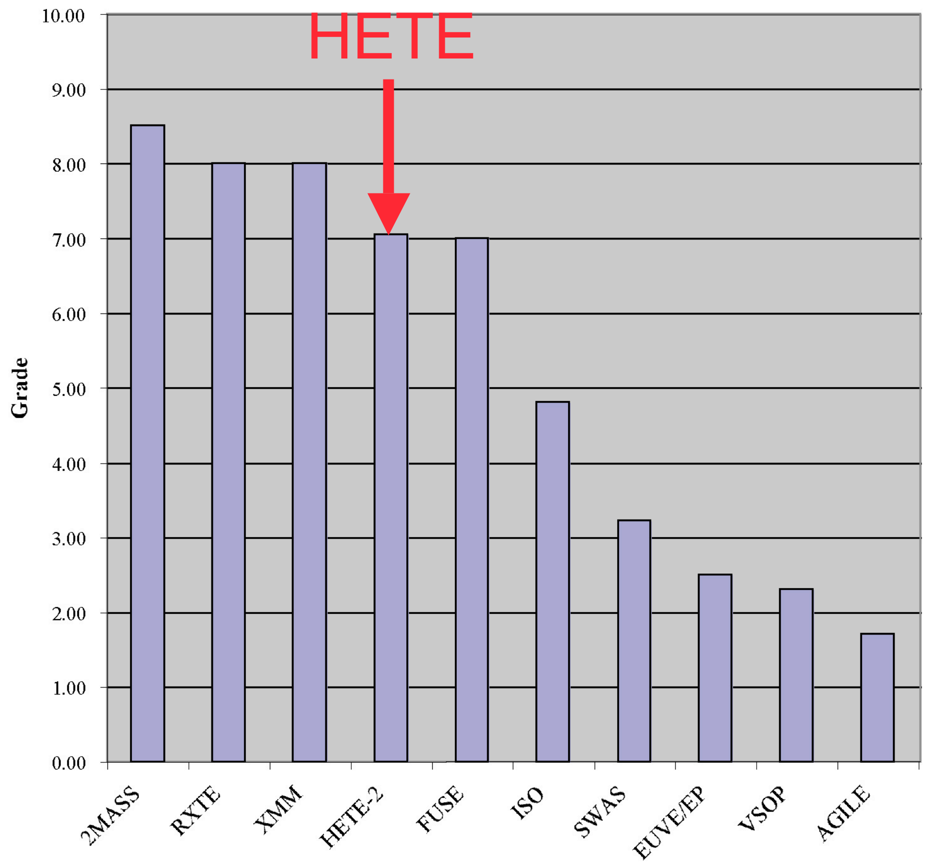
…HETE Team contends significant advances in 18 months since SR2002

Recommendation

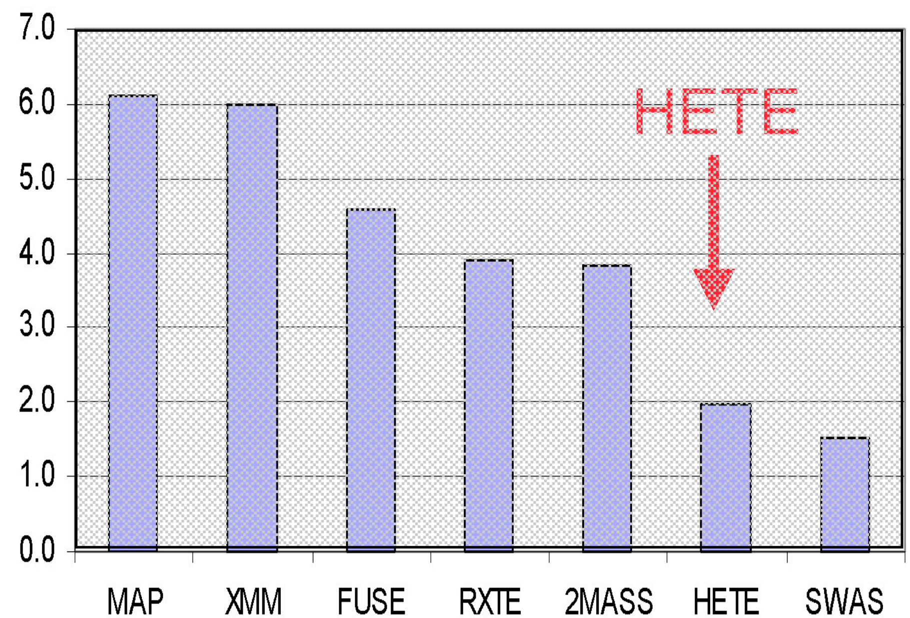
Qualitatively new advances in our understanding of gamma-ray bursts will require coordinated space- and ground-based efforts, and realistically **this goal will take a commitment to HETE-II until the start of the Swift mission**. Despite the relatively small, expected number of well-localized bursts, HETE-II provides a bridge to the Swift mission. **Specifically, we recommend funding of the HETE-II mission at the In- Guideline levels until January 31 2004,** with inclusion of the proposed Education and Public Outreach effort.

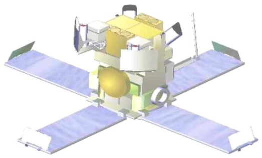
Senior Review Grades in 2000 and 2002

2000



2002





HETE MODA Program Activities-1

HETE Annual Operating Budget

- HETE MO&DA Budget is $1.9 M per year (full cost accounting)
- 3/4 for mission operations, 1/4 for science data analysis

Supports the following tasks, which are managed and coordinated at MIT:

MIT Mission and Science Operations Center

- Schedule commands and data acquisition for >13,000 primary ground station passes per year, providing 40 GB per year of raw telemetry
- Log and forward alerts from ~70,000 burst alert station passes per year

"Commercial cost" would be ~$20M at $200/pass.

- Compute and maintain satellite ephemerides using on-board GPS system
- Maintain and update satellite flight software
- Prepare and check satellite command loads
- Determine and maintain sun-, magnetic-, and star-derived realtime aspect files
- Maintain 1.3 TB Working Science Archive
- Host website for HETE Mission
- Transfer HETE Data Products to the GSFC HEASARC
- Support team of HETE Duty Scientists (6; provides 24-7 coverage for mission)
- Coordinate Burst Science Activities in US, France, and Japan

HETE MODA Program Activities-2

HETE Burst Alert Network

- Dedicated, automated VHF receivers at 14 Sites: Ascension, Gabon, Malindi, Bangalore, Singapore, Palau, Bohol, Kwajalein, Kiritimati, Maui, Marquesas, Galapagos, Cayenne, and Natal
- Maintain and monitor RF signals and Internet connectivity from each site to MIT
- Hardware and software maintenance and upgrades at 14 sites, in coordination with our Brazilian (1 site), French (2 sites), Indian (1 site), Italian (1 site), and Japanese (3 sites) colleagues

HETE Primary Ground Stations

- Dedicated, automated S band dishes at 3 sites: Singapore, Kwajalein, and Cayenne
- High speed Internet connection from each site to MIT for 10MB/pass
- Hardware and software maintenance and upgrades at 3 sites, in coordination with our French (1 site) and Japanese (1 site) colleagues

HETE Science Instruments

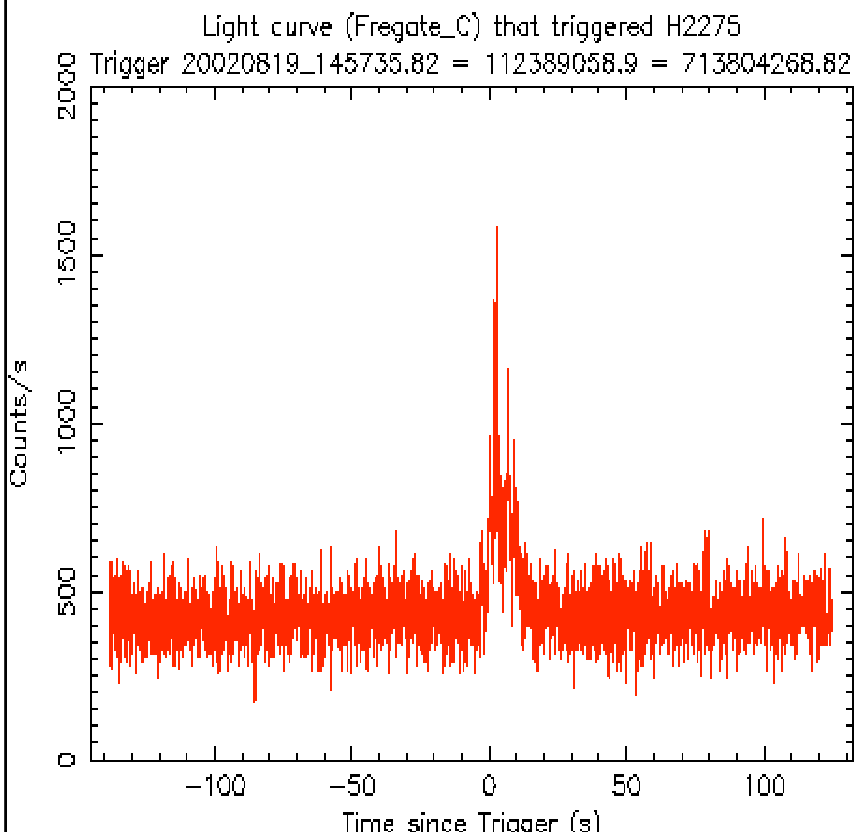
- Reduce and analyze data from Fregate (4 units), WXM (2 units), SXC (2 units) and Optical Cameras (4 units)
- Inter-calibrate localization data from all 4 science instruments
- Calibrate and maintain detector spectral response matrices (DRMs) for Fregate, WXM, and SXC

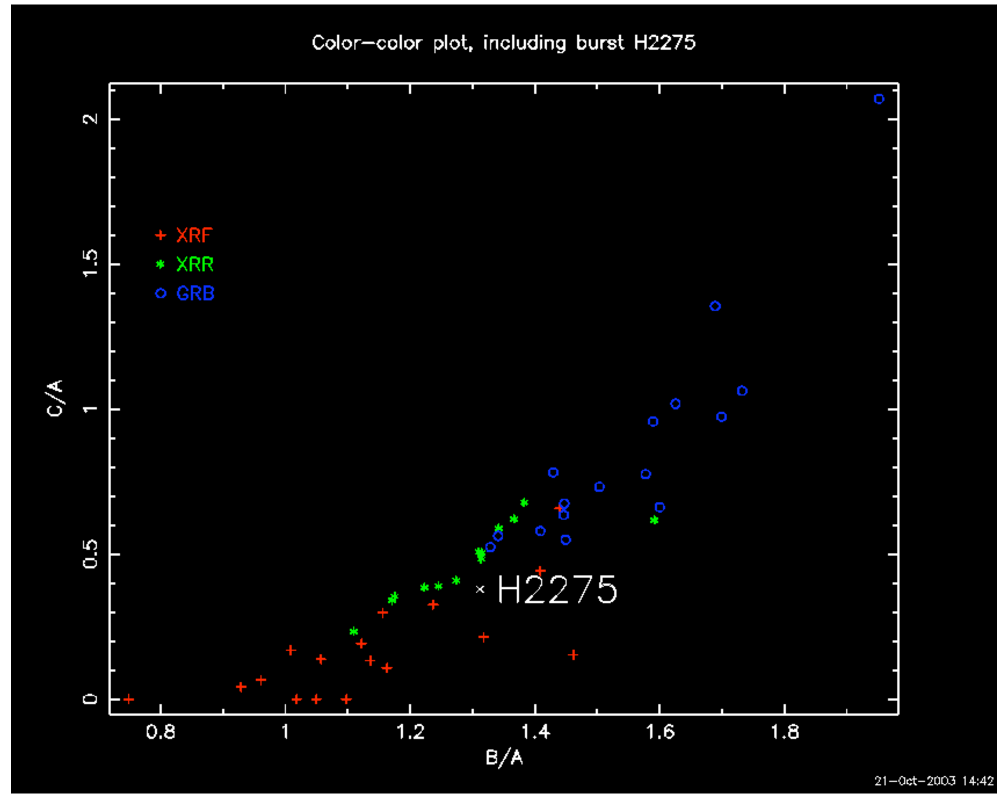
HETE Science Team

- Coordinate activity by core team members in US, France, and Japan
- Analysis of burst and background events from three HETE high energy science instruments
- Publication of individual burst papers, as well as catalogs

GRB020819(=H2275): Example from HETE Burst Summary Web Page

(http://space.mit.edu/HETE/Bursts/GRB020819/)



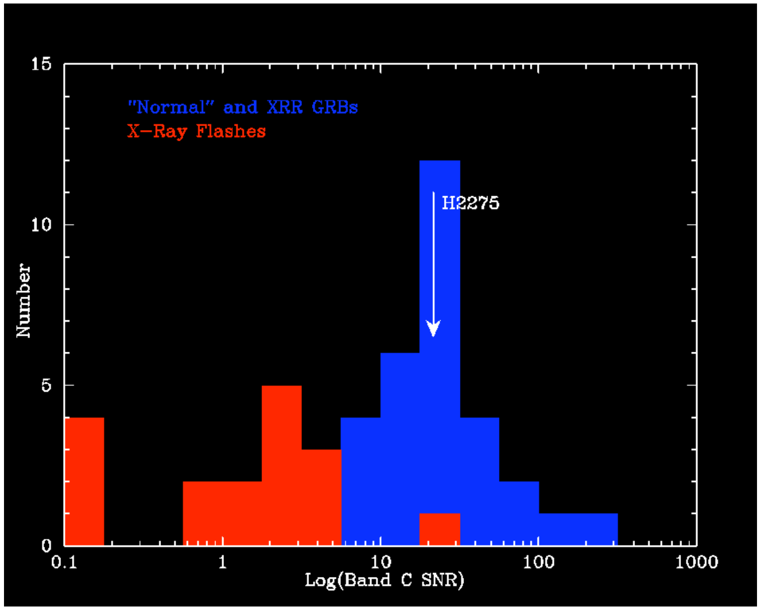


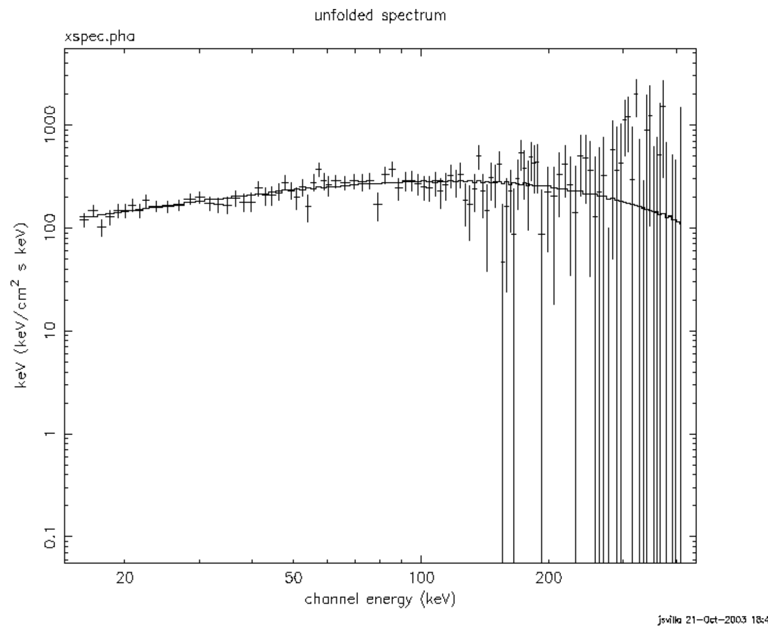
Left: Download ASCII table of Fregate Band A, B, C lightcurves here.

Right: The color of trigger H2275, defined by the ratio of total counts in Fregate band C (30-400 keV) to band A (7-40 keV) vs. band B (7-80 keV) to band A, overlaid on a the color-color plot of all localized bursts detected to date. Note the separation of XRFs, XRRs, and GRBs.

GRB020819(=H2275): Example from HETE Burst Summary Web Page--Cont'd

(http://space.mit.edu/HETE/Bursts/GRB020819/)





- **Left:** The signal to noise in Fregate band C (30-400 keV) of trigger H2275 in relation to the S/N of band C of other localized HETE triggers. We find empirically that most XRFs are faint and soft: the fact that localized bursts require a minimum S/N in the 2-25 keV band means that the band C S/N should be low. We find a cutoff in the band C S/N of 6.5 delineates the XRF/non-XRF population with high reliability.
- **Right:** An automated fit of a cutoff power-law spectrum has been performed for H2275. The fit of the model to the data is shown below; the calculated values of Epeak and the burst fluence (30-400 keV) are:

```
Epeak    = 116.47 keV
Fluence  = 1.188e-05 erg/cm^2
Duration = 23.200 seconds
```